CHANGES IN SANDSTONE DISTRIBUTIONS BETWEEN THE UPPER, MIDDLE, AND LOWER FAN IN THE ARKANSAS JACKFORK GROUP

A Thesis

by

CLAYTON PRYOR MACK

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2009

Major Subject: Geology

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Approved by:

Co-Chairs of Committee,	Arnold Bouma
	William Bryant
Committee Member,	Yuefeng Sun
Head of Department,	Andreas Kronenberg

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ABSTRACT

Changes in Sandstone Distributions between the Upper, Middle, and Lower Fan in the Arkansas Jackfork Group. (May 2009)

Clayton Pryor Mack, B.A., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Arnold H. Bouma
Dr. William Bryant

This study is a statistical analysis of the sandstone distribution within the Arkansas Jackfork Group which is a passive margin fan complex. Passive margin fan systems are typically associated with long fluvial transport, fed by deltas, wide shelf, efficient basin transport, that result in a bypassing system. Passive margin fans are generally fine-grained, mud rich, and well sorted. These fans can be separated into three units (upper, middle, and lower fan) based on their location within the fan and how the sediments are deposited. Five outcrops from the Arkansas Jackfork Group have been chosen for this study and each were divided into different facies dependent on sandstone percentages in certain bed sets. The amount of sandstone for each facies was calculated and a statistical approximation for each outcrop was determined. Sandstone distribution curves were made for each outcrop to show a graphic representation of how the sandstone is dispersed.

After analyzing different upper, middle, and lower fan outcrops, it is clear there is an obvious change in the sandstone percentage and distribution. The upper fan deposit has an overall sandstone percentage of approximately 77.5% and is deposited in beds

that are mainly amalgamated; 10-30m thick. Sandstone is deposited moderately even and is quite concentrated throughout the exposure. The middle fan outcrops contain approximately 72.6% sandstone and show similar patterns, except that the amalgamated sandstone beds are not as thick, 5-15m and contain more shale in between layers. As expected the lower fan outcrop is completely different in both sandstone percentage and distribution. The lower fan has approximately 65.4% sandstone. The distribution of sandstone is more concentrated in each of the individual units, or systems, but the overall complex has two systems separated by a massive marine shale bed, 33.5 m, that contains virtually no sand.

DEDICATION

I would like to dedicate this thesis to my wife, Andrea Mack and to my parents, Glen and Gerre Mack. Without them, I would not be who I am and where I am today.

ACKNOWLEDGEMENTS

I would like to personally thank my committee chair, Dr. Arnold H. Bouma, for all of the help you gave me in understanding everything I needed to know about deep-water Sedimentology. I am also grateful for the many days you spent with me in the field and how it was never a burden to hop in a car and drive to the outcrops 10 hours away just to answer questions. I would also like to thank my committee members, Dr. Bryant, and Dr. Sun, for their direction and assistance throughout the course of this research.

Thanks also go to Doug Hanson of the Arkansas Geological Survey for all of his time in the field and the helpful conversations on the Jackfork Group and the geology of the Ouachita Mountains. As for the Arkansas Geologic Survey, I give thanks for the use of your library as well as all of the supplies and coffee I needed.

Special thanks go to my field assistants Michael Riettini, Andrew Hutto, and Bryan McDowell for helping me collect my data. I also want to thank all of the people outside of my committee that helped edit my thesis; Will Dugat, Chris Klug, and my good friend Liz Raines. I also would like to recognize my friends and colleagues at Texas A&M University for making my college life exciting and interesting.

Finally, thanks and a debt of gratitude to my wife for her support and encouragement, without her none of this would be possible.

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CHAPTER I

INTRODUCTION

Overview

The Arkansas Jackfork Group is a Late Pennsylvanian submarine fan system which was the first recognized flysch deposit in North America. DeVries (1992) compared active margin submarine deposits in California and passive margin submarine deposits in Arkansas. At the time of his research, those two terms, active and passive, were not used to describe submarine deposits. According to Bouma (2000), active margin settings are “characterized by a short continental transport distance, narrow shelf, and a canyon-sourced, nonefficient basin transport system that results in a prograding type of fan.”, and a passive margin setting is associated with “long fluvial transport, fed by deltas, wide shelf, efficient basin transport, resulting in a bypassing system.” More comparisons between the active and passive turbidite fan systems can be found in Table 1. The Jackfork Group is a passive margin submarine fan complex that has been categorized as fine-grained and mud-rich (Bouma, 2000). A series of passive margin fans of the Jackfork Group outcrops provide to study the differences between the upper, middle, and lower units of a turbidite system. The other majority of past research on these outcrops has basically focused on specific parts of turbidite deposits. Specific research includes Slatt and Stone (2001) who use gamma ray logs to help

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This thesis follows the style of *AAPG Bulletin*.

understand different elements of deposition within the Jackfork Group and use as a reservoir analogue to similar deposits in Oklahoma. Miola and Shanmugam (1984) use the Jackfork Group to distinguish different flow types that occur during submarine fan sedimentation. Morris (1977) describes different flysch facies and interprets how the sediment was deposited. The purpose of this study is to focus on the changes in sandstone distribution throughout a passive margin turbidite complex.

Study Area Location

A series of outcrops of the Jackfork Group, shown in Figure 1, are exposed along the base of the Ouachita Mountains and have been folded and faulted by the Late Pennsylvanian Ouachita Orogeny. The series of outcrops begin in Little Rock, Arkansas and prograde southwest towards Texarkana at the base of the Ouachita Mountains.

Outcrops studied (Figure 2):

1. Big Rock Quarry: upper fan
2. Friendship Quarry: middle fan
3. Lake DeGray Lake Spillway: middle fan
4. Hollywood Quarry: middle fan
5. Kirby Quarry: lower fan

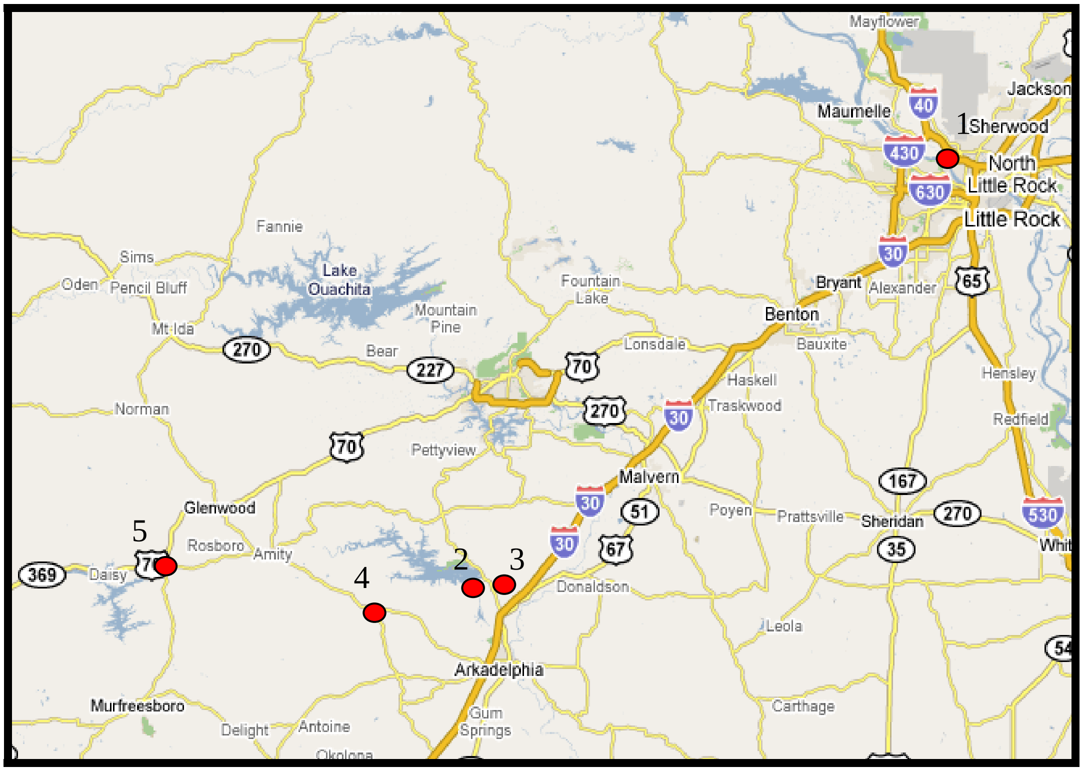

Figure 1: State map of Arkansas showing geographic location of outcrops. 1) Big Rock Quarry, 2) DeGray Lake Spillway, 3) Friendship Quarry, 4) Hollywood Quarry, 5) Baumgardner Quarry (modified from Google, 2008)

Objectives

The objectives of this research are as follows:

1. Physical analysis of each used outcrop with respect to the approximant amount and distribution of sandstone.
2. Identify facies based on sandstone percentages.
3. Direct comparison of the upper fan outcrop, three middle fan outcrops, and the lower fan outcrop to see what changes occur in sandstone percentage and distribution.

Methodology

The five outcrops have been divided into three divisional parts of this turbidite complex: upper, middle, and lower fan. Each part has been divided into different facies based on sandstone percentage and distribution that can be seen in outcrop, core, and wire line logs. Facies Architecture is established by observing stacking patterns of the sand beds. The overall outcrop sand/shale ratios are calculated by averaging the individual Sand/Shale Ratios for each facies. The facies are determined by the arrangement and amount of different types of lithofacies. Lithofacies observed in outcrops are as follows:

1) Massive fine-grained sandstones.
2) Shale intraclast breccias/conglomerates with a sandy matrix (sandy debrites)
3) Shale intraclast breccias/conglomerates with a muddy matrix (muddy debrites)
4) Finely laminated shales.

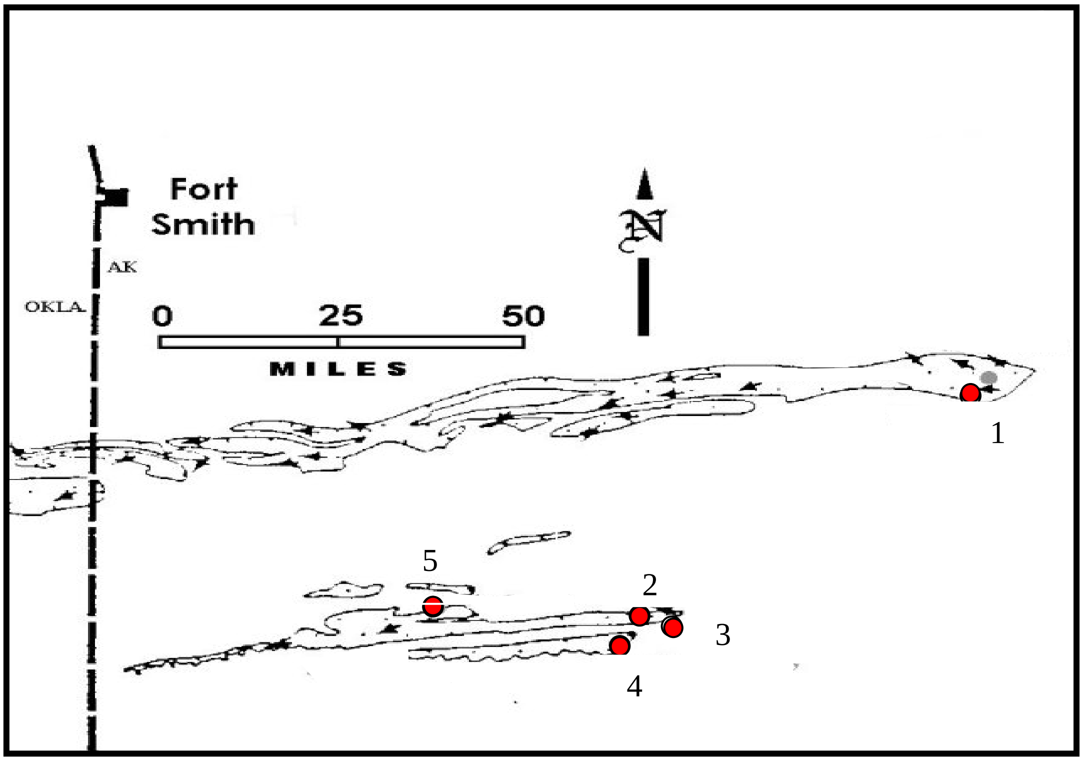

Figure 2: Map showing outcrop locations and paleoflow indicators. 1) Big Rock Quarry, 2) DeGray Lake Spillway, 3) Friendship Quarry, 4) Hollywood Quarry, 5) Baumgardner Quarry (modified from Bouma and Stone, 2006).

Table 1: A comparison between active and passive margin types (modified from Bouma, 1997).

Types of controls and characteristics	Active margin	Passive margin
Tectonic influence on basin Type of margin Location of receiving basin Relative size of basin	High Active margin Typically on oceanic crust Often small to medium	Low Passive and some active margins Usually on continental crust Often medium to very large
Length of subaerial transport Width and type of coastal plain Width of shelf	Relatively short Narrow: mountainous Normally narrow	Usually long Wide and flat Normally wide
Type of feeding basin Sand/clay ratio of input sediment Volume of sediment input Main grain size of input sediment	Canyon-fed High Small to medium Medium sand & coarser	Delta-fed Relatively low Medium to large Fine sand & finer
Type of basin transport Type of depositional fan Size of gravity flows	Non-efficient Gradually prograding Normally small	Efficient Much "bypassing" to lower fan Mainly medium
Sand/shale ratio of turbidite systems Shale between turbidite stages Shale between turbidite layers	High Normally thin Thin, fine sand & silt rich	Relatively low Normally thick Thin, silt rich
Main area of sand deposition Active live of major channels Size of channels	Upper and mid fan Low to medium Medium	Outer fan Good Normally large
Developments of levees Type of sediment on levees Sedimentary structures in levee	Moderate to good Bedded sands, some silts Parallel, current ripple, & climbing ripple	Normally very good Thin bedded sand-mud Parallel, current ripple and climbing ripple
Possibility of slumping Number of canyon tributaries Development of distributaries	Small to good Few to several Good	High One to very few Reasonable
Overbank sediment type Main sediment of lower fan Chance of fan becoming exposed Type of sediment of canyon fill	Sand Sand to silt-rich mud Rather good Sand-rich with sand & silt-rich shales	Silty mud-clay mud Fine sand Reasonably poor Fine mud, sometimes with sandy slides
Sand/shale ratio base-of-slope Sand/shale ratio channel fill Sand/shale ratio mid fan Sand/shale ratio outer fan	High High Medium to high Low	High High Low High
Influence of climate Orientation of basins Influence of sea level fluctuations Type of channel fill	Low to medium Often parallel to shore Low to moderate Gravel, sand, some mud	Commonly high Often directed offshore High Sand with/without mud
Reservoir potential Horizontal conductivity Vertical conductivity	Often high Often high Good	Medium to high Medium to high Low to medium or tortuous

CHAPTER II

PREVIOUS STUDY

Regional Stratigraphy

The Ouachita Mountains in Arkansas are exposures of folded and faulted Paleozoic strata, shown in Figure 3. According to Tillman (1991), The Ouachita Mountains outcrop rocks ranging from lower Paleozoic to Pennsylvanian in age. Before being uplifted and eroded, the total sediment thickness was approximately 17,000 feet thick, and 80% of the strata belonged to the Carboniferous Stanley, Jackfork, Johns Valley, and Atoka Formations (Coleman, 2000). The Jackfork Group was described by Moiola and Shanmugam as a westward dipping longitudinal submarine fan system (De Vries, 1992) that consists of thick deposits of fan channel and fan lobe sandstones. Paleo-flow indicators show that the depositional axis in the Ouachita trough trends in an east to west orientation (Tillman, 1991). The Jackfork Group overlays the Mississippian Stanley Group and has been described as a high stand, starved basin.

The Stanley Group contains quartz rich sediment from a northern and eastern source, as well as from a southern source that is explained to be volcanic debris from the onset of a subduction zone. The Stanley Group is considered to be the first unit that shows signs of submarine clastic input into the Ouachita trough (Tillman, 1991).

Overlying the Jackfork is the Jones Valley Shale. This unit of sediments has been interpreted as a slope to basinal deposit of muds that contain shelf-derived, exotic cobbles and boulders that slid or slumped into the basin (Tillman, 1991).

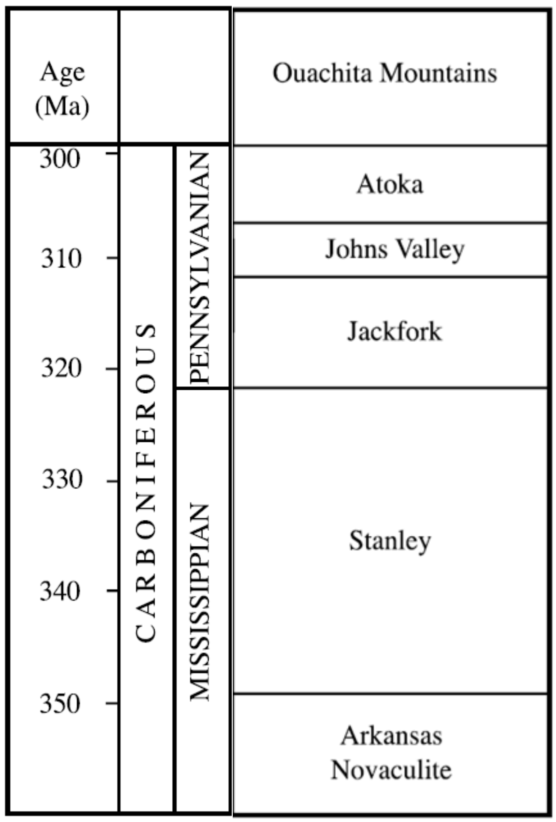

Figure 3: Chronostratigraphic chart of the Ouachita Mountains (modified from Ethington et al., 1989).

Tectonic History

Before the Stanley Formation was deposited, the Ouachita Basin was a passive margin that resembles the Gulf of Mexico today, (Golob, 2003). Figure 4 shows the structural evolution of the Ouachita trough beginning in the early Devonian. During the early Devonian, the Ouachita trough was at its deepest;

Arkansas Novaculite was deposited to a thickness of 940 feet in 71 million years (Hass, 1951). In the early Mississippian the deposits switched from preorogenic to synorgenic as the South American Plate began to drift north toward the North American craton. During the early to middle Atokan, the synorgenic deposits started to thrust onto the North American plate initiating the formation of the Ouachita Mountains, ending during the middle Pennsylvanian (Golob, 2003).

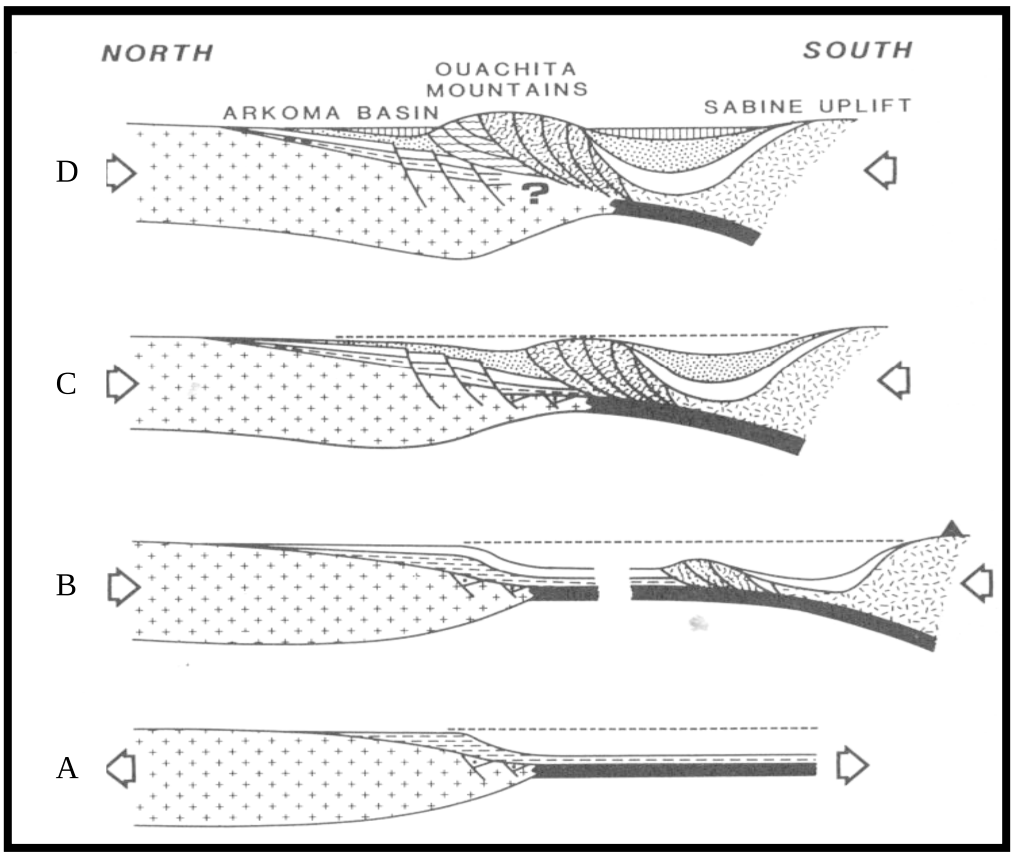

Figure 4: Structural history of the Ouachita basin, A) Deposition time Arkansas Novaculite, early Devonian through earliest Mississippian. B) Depositional time of the Stanley Group, Jackfork Group, and Johns Valley Formation, early Mississippi through earliest Atokan. C) Depositional time of the Atoka Formation, early through middle Atokan. D) Formation of the Ouachita Mountains ends during the middle Pennsylvanian (modified from Golob, 2003).

Sediment Source Areas

According to Sutherland (1988) there are two main clastic sediment source areas for the Ouachita Basin. These sources were determined based on petrographic analysis, regional facies distributions, and paleocurrent data. The first of these sources was the Black Warrior Basin to the east and southeast, which deposited lithic arenites. The second main source area was the Illinois Basin to the north of the Ouachita trough that deposited mostly quartz arenites. Most of the sediments from these two sources bypassed the shelf and were deposited on the ocean basin. A third minor source area was from the microcontinent Llanoria that was positioned south of the Ouachita Basin (Golob, 2003). According to Danielson et al. (1988), this source provides lithic fragments and conglomeratic sandstones and is more pronounced in the Upper Jackfork outcrops.

Passive Margin System Model

Because coarse-grained, sand-rich and fine-grained, mud-rich turbidite systems represent two different end-member types, the two types turbidite deposits fall partly in different geographic locations. From Bouma et al. (2006), the two types of systems are controlled by tectonics, climate, sea-level fluctuations, and sediment processes. The Jackfork Group has been characterized as a fine-grained passive margin system (Bouma et al., 2006), therefore this study will focus only on the passive margin system. Figure 5 illustrates the Bouma (2000) model for fine grained systems. His model for fine-grained, mud-rich systems was based on several studies mainly on the modern Mississippi fan, the Jackfork Group in

Arkansas, and the Tanqua Karoo Subbasin in South Africa with many student studies. This model breaks the system up into a three major parts:

1. Upper Fan
2. Middle Fan
3. Lower Fan.

Upper Fan

The upper fan starts at the bottom of the continental slope and ends a little further at the basin floor where the slope gradient is less dramatic. The canyon feeders are distinctive erosional features formed by massive slides and slumps that funnel sediment down the slope, shown as A-A’ on Figure 5. These erosional features are generally the last part of the system to be filled and are usually filled with local sand deposits and muds (Bouma, 2000). The lower portion of the upper fan is called the base-of-slope. The base-of-slope is considered the transition zone. This transition occurs from the base of the inflection of a lower gradient of the continental slope, to the beginning of the basin floor. Because there is a change in slope, flow velocities slow, and the coarser material is deposited. Bouma (2000) describes the fill of the conduit, as stacked wide and thin channel fills that can have preserved sand-rich levee and minor over-bank deposits, shown by the cross-section B-B’ in Figure 5. Each successive channel cuts into older channels. The base-of-slope conduit may be up to 10 km wide (Bouma, 2000).

Middle Fan

The middle fan is defined as the location in the system when the channel system goes from multiple channel feeders to one large channel feeder (Bouma, 2000). The middle fan can have two types of channel deposits: type 1, which has an aspect ratio, channel width to depth, less than 50, and type 2, which has an aspect ratio minimum of 150-200. The channel types change due to the fact that channels become wider and shallower with distance (Kirschner and Bouma, 2000). Along with channel deposits, the middle fan also has levee-overbank and crevasse splay deposits. Figure 6 demonstrates how these channels migrate laterally as the system evolves, and C-C' in Figure 4 shows how the system builds vertically.

Lower Fan

The boundary from the often long middle fan to the lower fan is transitional and can vary greatly due to differences in individual flows and overall travel distance. Smaller flows will not travel as far as larger flows and therefore there can be lower fan deposits mixed among middle fan deposits. Variations are influenced by other conditions besides flow size, including sea level fluxuations and sediment concentrations (A. H. Bouma, 2008, personal communication). The lower fan is divided into two parts. The upper portion of the lower fan is defined by the presence of distributary sheet sands. These deposit large and small thin laminated sands. The sheet sands and lobe deposits form in the lower portion when turbidity flows become unconfined by a channel. These deposits can form laterally extensive compensational stacked beds, shown by D-D' on Figure 5. These deposits can be amalgamated and/or separated by hemiplegic sand or muds depending on the turbidity flows (Golob, 2003). Because avulsions width is very wide in the lower fan compared to the larger middle fans, each sandstone package can be separated by thick intervals of marine shales. At the end of the lower fan, certain thicknesses may be different per location. Nevertheless, when a deposit obtains a certain thickness, the outer fan will change from massive to finger deposition and rapidly stops, shown by E-E' on Figure 5.

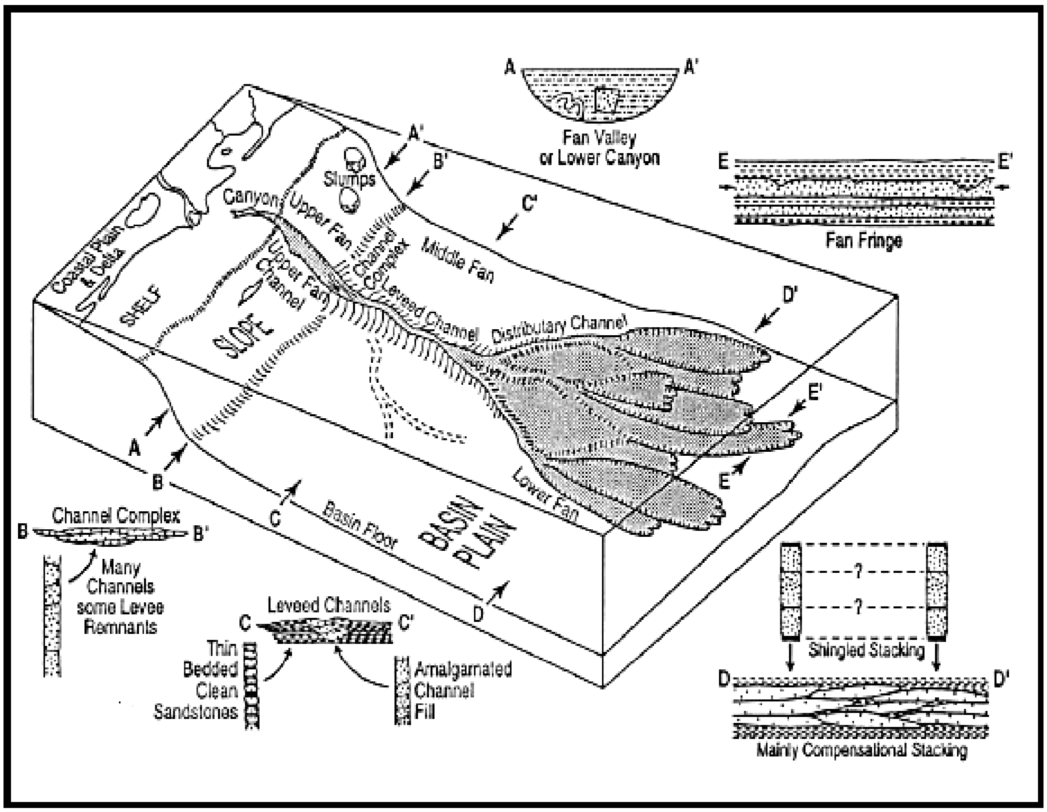

Figure 5: **Cartoon of a fine-grained turbidite system model (modified from Bouma, 2000).**

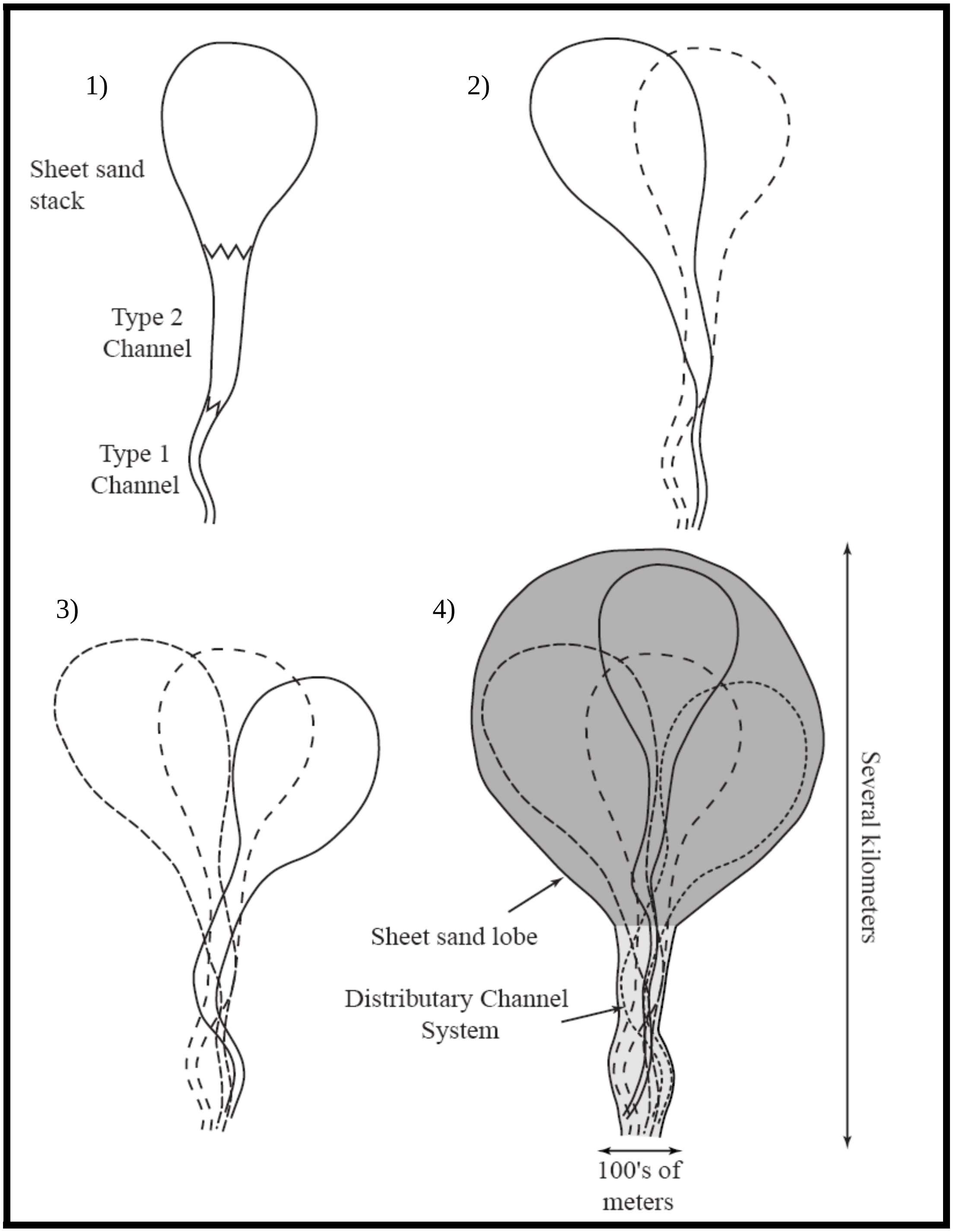

Figure 6: Diagram illustrating avulsions of middle fan channels and sheet lobes. (1) Illustration of type 1 and type 2 channels associated with the middle fan shown with an attached lower fan stack of sheet sands. (2) and (3) show lateral switching and evolution of multiple fans through time. (4) Lateral and down-dip scale of a fan system (modified from Kirschner and Bouma, 2000).

CHAPTER III

OUTCROP DESCRIPTIONS

Upper Fan

The best outcrop in the upper fan is the Big Rock Quarry. The outcrop contains deposits from the lower portion of the base-of-slope. As mentioned in Chapter II, the base-of-slope section is where deposition begins and multiple feeders are funneled into one conduit. The outcrop is considered to be located close to the source area.

Facies

Two different facies are present in the upper fan outcrop, Figure 7. They are as follows:

Facies U1

Facies U1 is a sandstone rich complex of amalgamated channels with a small amount of fine grained sediments, Figure 7. Along with sand filled channels, there are some mud-rich deposits that are described by Cook (1993) as muddy to sandy debrites. The majority of the sandstone beds are channel fills that are massive and structureless. Some individual beds do contain planer and cross laminations as well as liquefaction and water escape structures. The approximant percent of sandstone is 80%.

Facies U2

Facies U2 is observed by Slatt and Stone (2001) as offset-stacked channel-levee/overbank deposits caused by a decrease in accommodation space, Figure 7. Sandstone percentage for this interval is approximately 65%.

Big Rock Quarry

Big Rock Quarry is located directly adjacent to the Arkansas River in North Little Rock, Arkansas, and was used in the 1950's as a source of crushed aggregate. The outcrop exposure, shown in Figure 7, is 60m high and 900m long. The outcrop is described as a deposit of sandstone on top of an unknown thickness of basin floor marine shale (Stelting et al., 2004). Sandstone percentages and Sand/Shale Ratios have been calculated by Cook (1993), in great detail. For this study those measurements will be used because of a higher confidence in methodology; however, sandstone percentage and Sand/Shale Ratios have been remeasured to use as a comparison to those previous results.

Facies Architecture

This outcrop can be divided into 2 packages that represent a facies type, Table 2. Package A is defined as the base of the outcrop and package B is defined as the top of the outcrop.

Table 2: Data table showing package thickness and facies type for the Big Rock Quarry.

Package	Thickness (m)	Facies Type
A	48	U1
B	12	U2

Sand/Shale Ratio

The sand/shale ratio for this outcrop has been calculated by Cook (1993) and is determined by the amount of sand and shale present in each rock type found in the exposure. This was defined primarily on a core that was drilled by Shell Oil Corporation behind the quarry face. Below is an approximation of the different Sand/Shale Ratios for the rock types that are present in the outcrop. Note that the bottom third lithofacies was not cored, but is seen well in the outcrop:

1) Sandstones with a net:gross of 1.
2) Debrites with a net:gross of 0.5.
3) Thin interbedded sandstones and shales with a net:gross of 0.5.
4) Shales with a net:gross of 0.

The approximant percent of rock types in outcrop from Cook (1993) are 65.5% sandstones, 10% shale, 15.3% debrites, and 9.2% thin interbedded sandstones and shales. The sand/shale ratio for Big Rock Quarry and the only upper fan deposit is 3.5 with an approximately 77.75% total sandstone and 22.25% total shale.

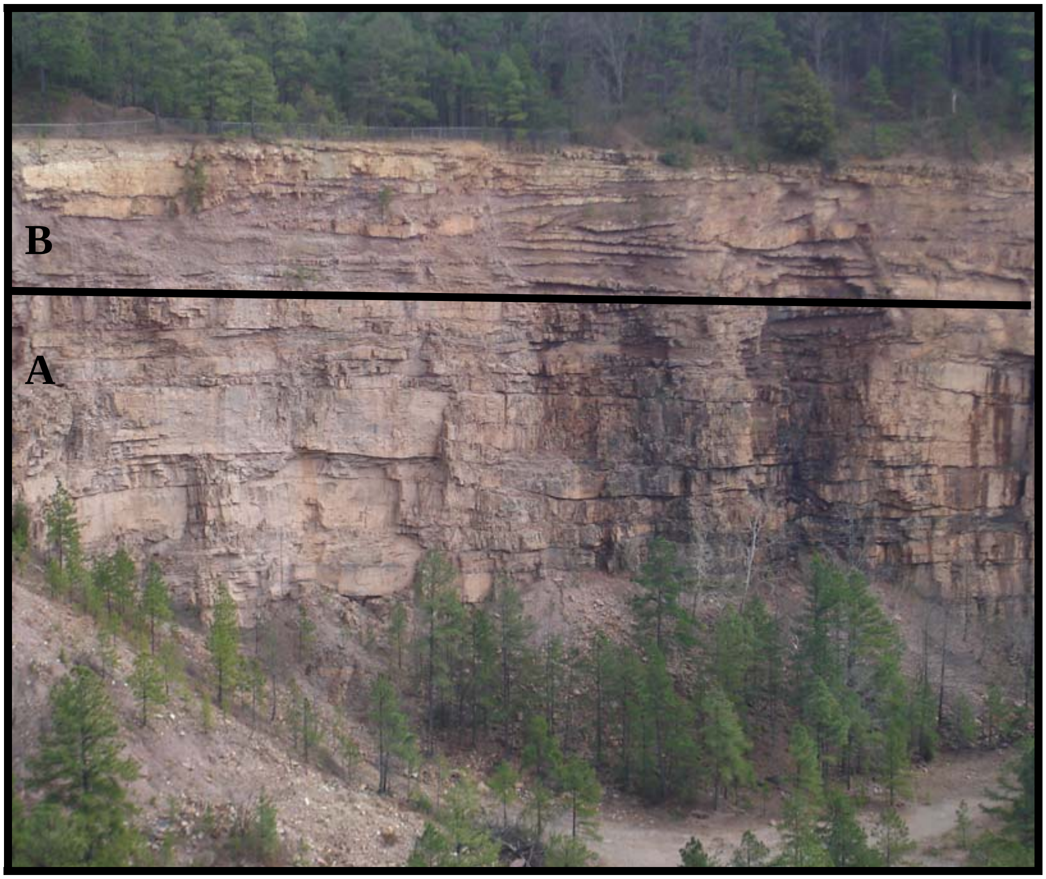

Figure 7: Outcrop photograph of Big Rock Quarry showing A, Facies U1 which is 48 m thick and B, Facies U2 which is 12 m thick.

Middle Fan

The set of three middle fan outcrops begin in a quarry in Friendship, followed by an outcrop in DeGray, and a quarry outside of Hollywood, refer to Figure 2 for locations. These series of outcrops are very closely spaced but because of the structural complexity, exact correlations are not possible. The only way to compare the outcrops may be to analyze sand/shale ratios and facies architecture patterns. However, the differences of the three outcrops make comparing a major guess because each fan, or flow, changes over rather short distances. As discussed in Chapter II, at the end of the middle fan there is a transition to the lower fan and the strong possibility of having middle and lower deposit types mixed. These middle fan outcrops assume that their location in the system is purely middle fan.

Facies

Four different facies are present in the middle fan outcrops. They are as follows:

Facies M1

Facies M1 is an amalgamated sandstone package that ranges in bed thickness from 30 cm at the base to 15 cm at the top, Figure 8. The approximant sandstone percent is 95% or more. The basal contact is sharp, and the top contact is gradational. The base of this facies can commonly be debrites. Deposits of this facies are associated with a channel axis environment.

Facies M2

Facies M2 is mostly amalgamated sandstone beds that are on the order of 6-30 cm thick and are mostly separated by thin laminated shales, Figure 9. Sandstone percentage for this interval is approximately 75%. The basal and top contact for this facies is gradational. Deposits of this facies are associated with a channel margin environment.

Facies M3

Facies M3 shows interbedded thin amalgamated sandstone and shales, Figure 9. The sandstone layers are on the order of 1- 20 cm thick separated by laminated shales. Sandstone percentage is approximately 50%. This facies is associated with levee-overbank deposits. The basal and top contacts for this facies are gradational.

Facies M4

Facies M4 is mostly hemipelagic muds with individual thin sandstone layers, Figure 10. Sandstone layer are millimeter to centimeter scale and sandstone percent for this facies is approximately 30%. This facies is associated with some distal over-bank deposits.

Facies M5

Facies M5 is a debris flow deposit or debrite, Figure 11. Middle fan debrites commonly have a shale matrix. Sandstone percent for this facies is approximately 50% and is deposited as a result of a failure on the levee walls.

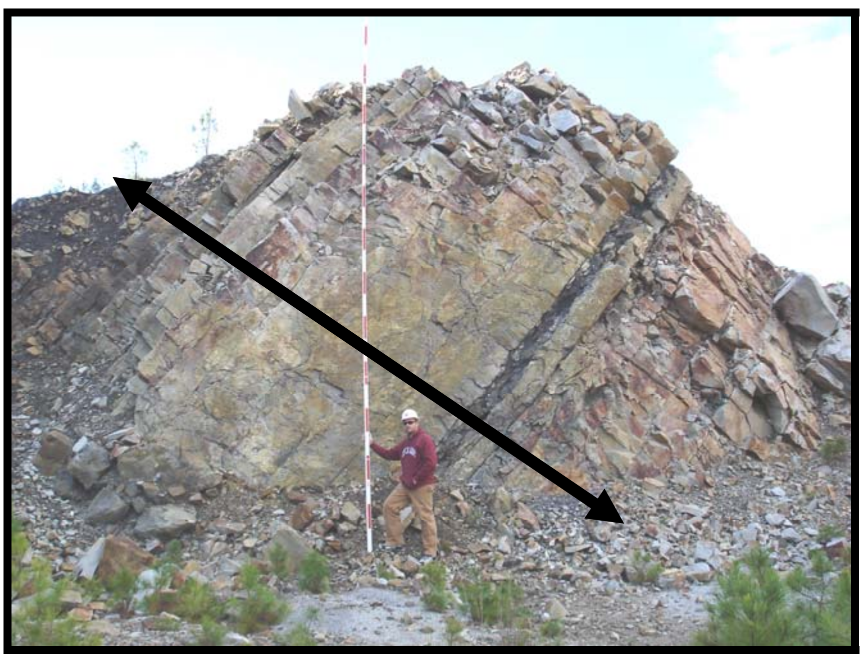

Figure 8: Outcrop photograph from the Friendship Quarry of a Facies M1 that is 8.5 m thick.

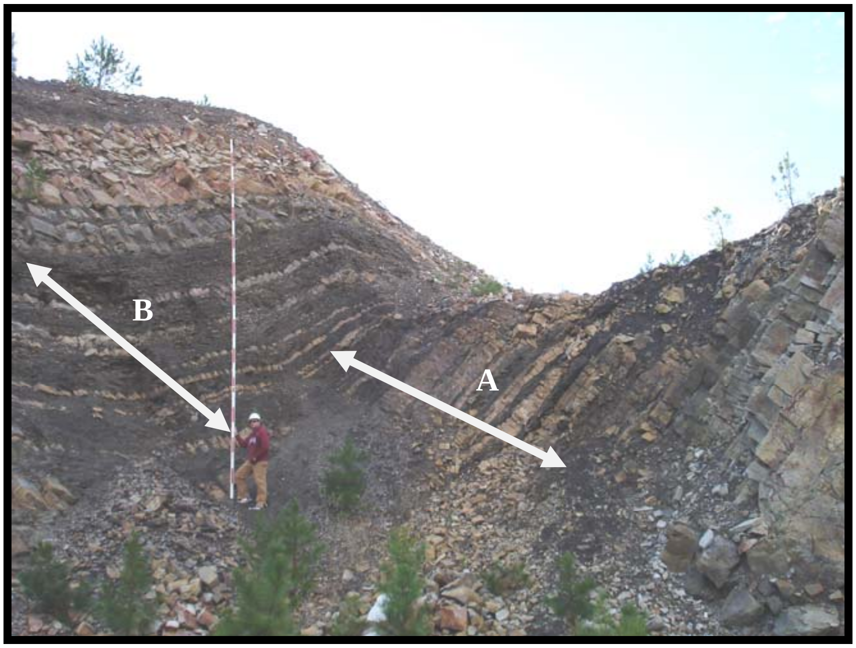

Figure 9: Outcrop photograph from the Friendship Quarry showing A, Facies M2 that is 4m thick and B, Facies M3 that is 6.5 m thick.

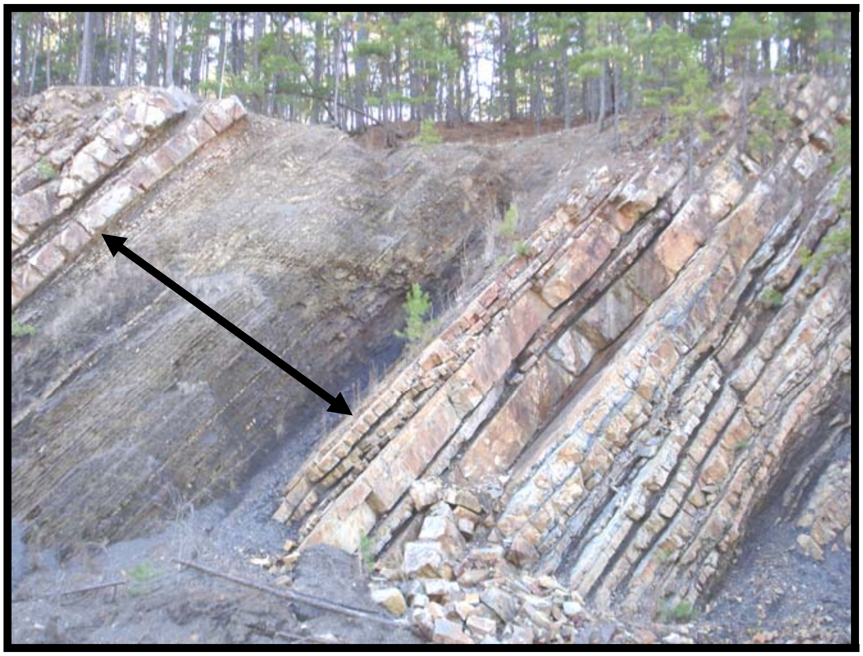

Figure 10: Photograph from the west wall of the DeGray Lake Spillway showing a Facies M 4 that is 10.3m thick.

Figure 11: Photograph from the East wall of the DeGray Lake Spillway showing a Facies M 5 that is 6.5m thick.

Friendship Quarry

The Friendship Quarry (outcrop 3 on Figure 2) is located about 55 miles south west of the Big Rock Quarry and is located a few miles Northwest of Friendship. This quarry is owned by Martin Marietta Materials and is used as a source for road aggregate for the Hot Springs County Road Department. The quarry exposes an approximant strike cross section 25 m thick and a dip cross section over 600 m in length with beds tilted 40 degrees along strike, Figure 8. It can be seen from Figure 9 that down dip thickness does not change drastically.

<u>Facies Architecture</u>

As shown on Figure 12, this outcrop can be divided into 5 total packages each representing a facies type, Table 3. Package A is defined as the base of the outcrop and package E is at the top of the outcrop. Package A is separated by a thin, 20 cm, muddy debrite. The debrite is grouped into this package because of how thin the interval is and because it is could considered a minor local episode.

Table 3: Data table showing package thickness and facies type for the Friendship Quarry.

Package	Thickness (m)	Facies
A	8.5	M1
B	4	M2
C	6.5	M3
D	1.5	M2
E	3.5	M1

<u>Sand/Shale Ratio</u>

The sand /shale ratio for this outcrop is based off of the strike cross section exposed near the east end of the outcrop. Outcrop descriptions show a distribution of facies as 49% facies M1, 24% facies M2, and 27% facies M3. By using the sandstone percentages for each facies, the overall sandstone percent for the entire outcrop can be calculated. This comes out to be approximately 78% total sandstone and 22% shale and a sand/shale ratio of 3.5.

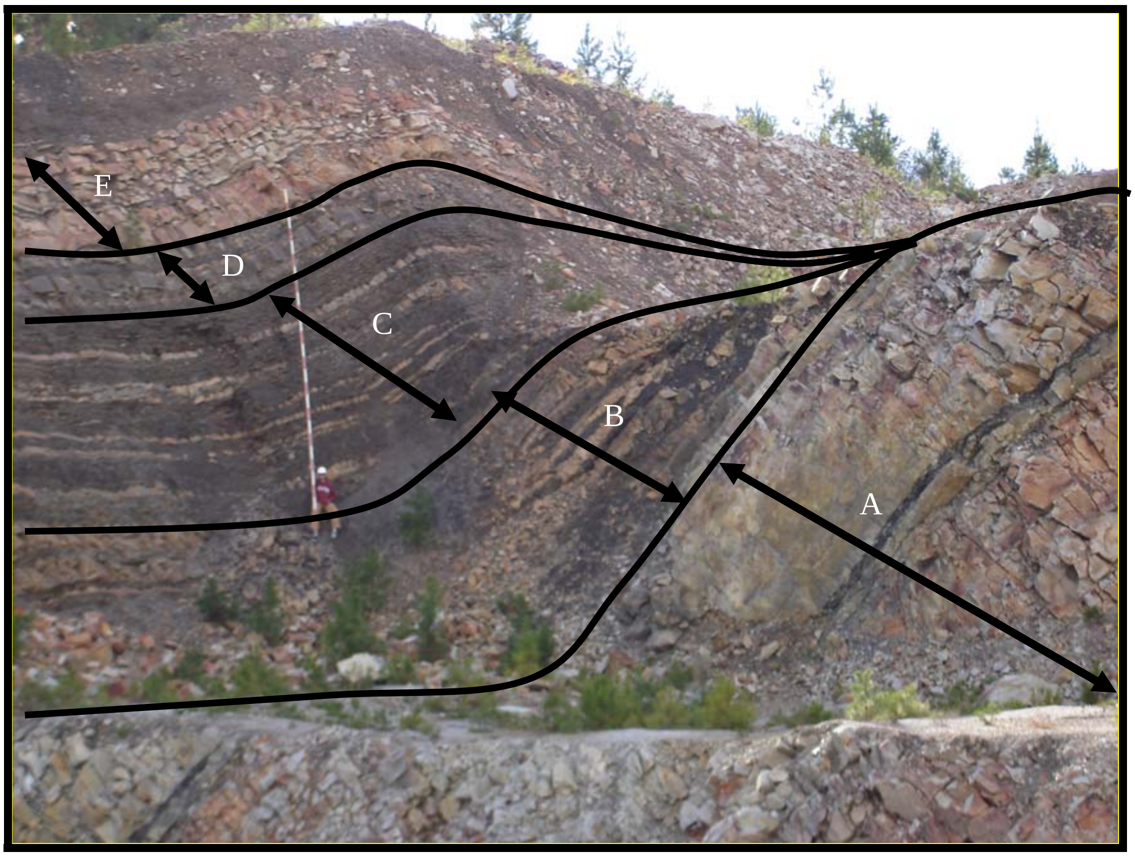

Figure 12: Photograph of Friendship Quarry outcrop showing units A-E; stratigraphic top is to the left.

DeGray Lake Spillway

The DeGray Lake spillway is located on the south end of DeGray Lake and is used as an overflow for the lake in case of flooding. This outcrop exposes two walls that run roughly north and south with an east wall and a west wall 65 m apart. The exposure is approximately 300 m thick and is conformable. Only 170 m have been measured due to the nature of the outcrop, Figures 13 and 14. The outcrop beds are tilted approximately 45^{o} from vertical. Many researchers have studied this particular outcrop to gain knowledge in understanding the processes and characteristics in submarine flows and deposits, especially for the reservoir characterization and as an outcrop analog. Researchers include: Morris (1971), Moiola and Shanmugam (1984), Breckon (1988), Slatt et al. (2000), and Stone and McFarland (1981). These studies on this particular outcrop have yielded many different interpretations about how the rocks were deposited, which has led to controversy about deep water deposits.

Facies Architecture

This outcrop can be divided into 17 total packages, each representing a facies type, Table 4. Package A is defined as the base of the outcrop and package Q is at the top of the outcrop.

Table 4: Data table showing package thickness and facies type for the DeGray Lake Spillway.

Package	Thickness (m)	Facies
A	15	M1
B	6.6	M3
C	5.6	M2
D	3.5	M4
E	9.1	M3
F	11.4	M4
G	3.9	M5
H	14.7	M3
I	9.3	M2

Package	Thickness	Facies
J	7.4	M4
K	6.6	M2
L	10.3	M4
M	12.5	M1
N	9.6	M2
O	6.5	M5
P	2.2	M3
Q	36	M1

Sand/Shale Ratio

The sand /shale ratio for this outcrop is based off the strike cross section exposed on the east wall of the outcrop. Outcrop descriptions show a distribution of facies as 37.3% facies M1, 22.2% facies M2, 15.3% facies M3, 19.2% facies M4, and 6% facies M5. By using the sandstone percentages for each facies, the overall sandstone and shale percent for the entire outcrop can be calculated. The outcrop contains approximately 68.5% total sandstone and 31.5% shale and a sand/shale ratio of 2.2.

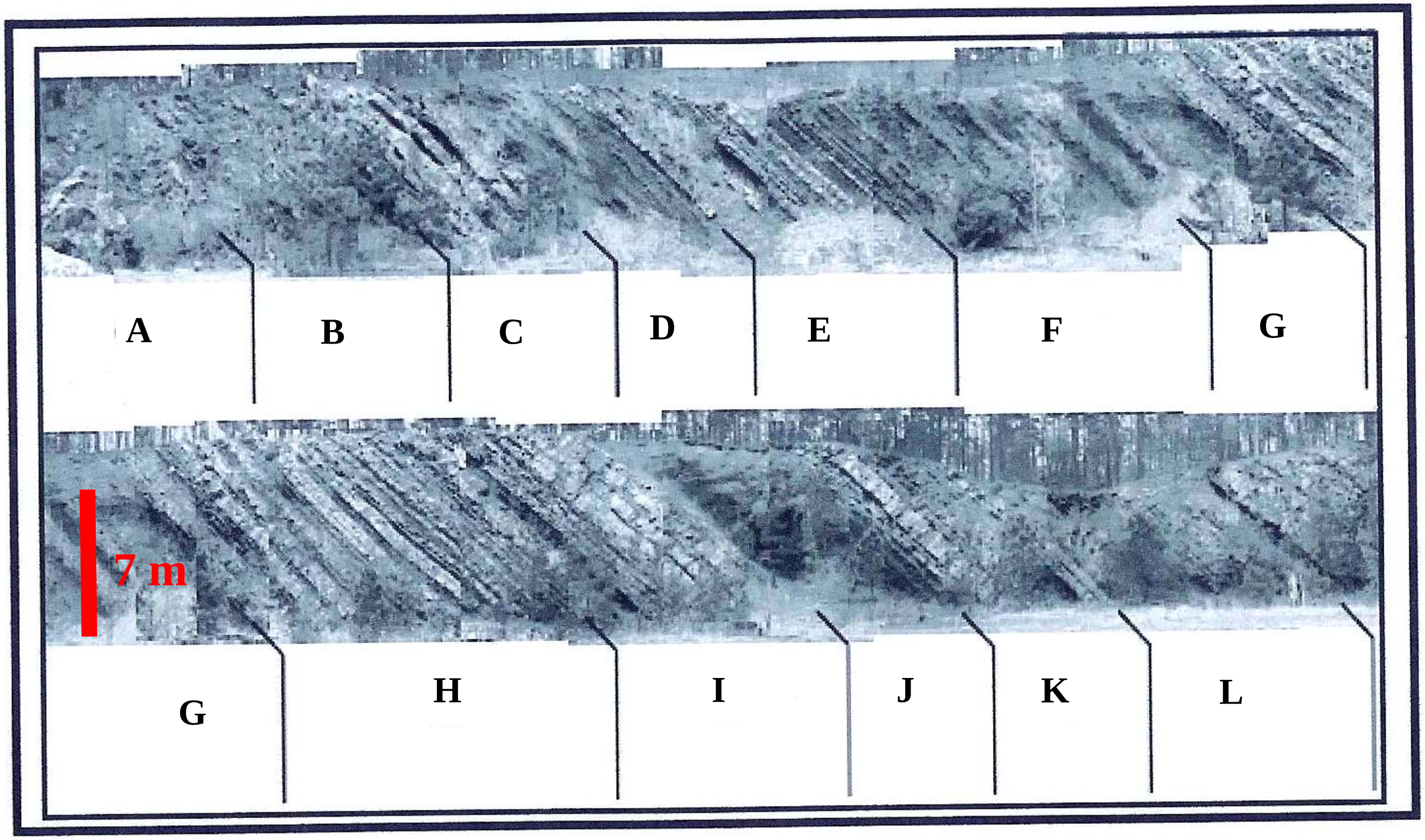

Figure 13: Photomosaic of DeGray Lake Spillway from the east wall showing units A-L. Lighter color is sandstone and the darker color is shale. Stratigraphic top is to the right (modified from Golob, 2003).

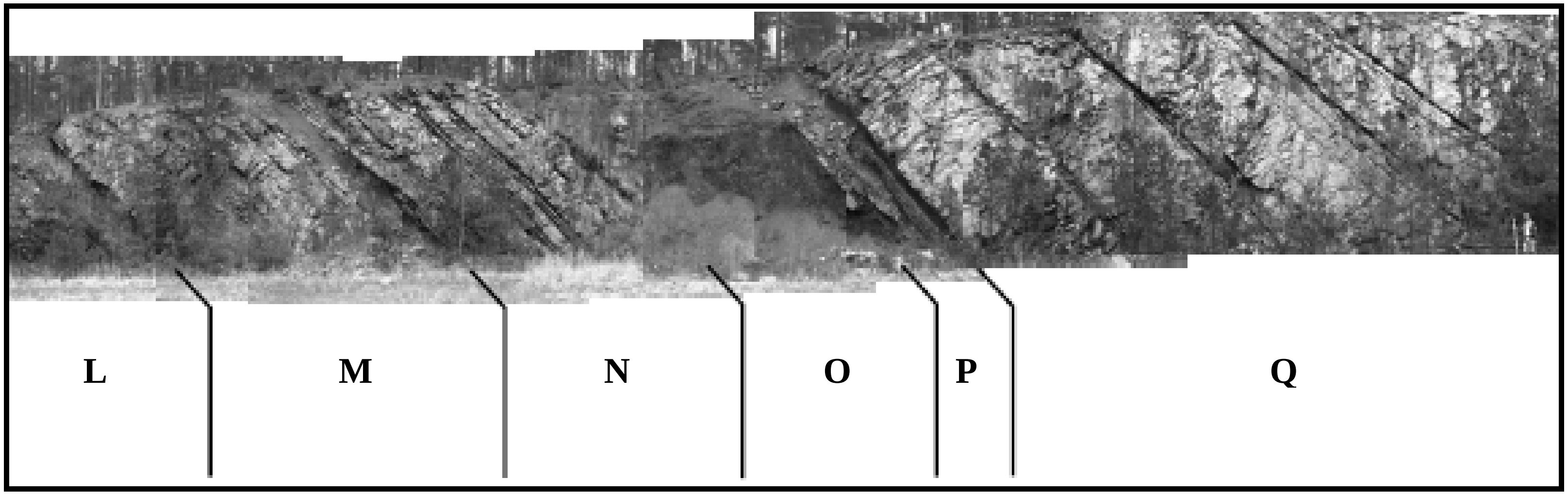

Figure 14: Photmosaic of DeGray Lake Spillway from the east wall showing units L-Q. Lighter color is sandstone and the darker color is shale. Note person on the right for scale and that stratigraphic is to the right (modified from Golob, 2003).

Hollywood Quarry

The Hollywood Quarry is located 3 mi north of the town of Hollywood, Clark Co., Arkansas. The outcrop is 380 m in length and 20 m thick, Figure 15. Bedding strikes N20-30^{o} and dips 11-16^{o} west. The quarry exposes a strike and partial dip cross-section due to the nature of how the outcrop was excavated. This outcrop is often used by the petroleum industry as an outcrop analog for Gulf of Mexico deep reservoirs (Goyenche et al., 2007). A 47 m core was drilled behind the quarry face and the description of that core was done by Goyenche et al. (2007) and is used for sandstone percentages and sand/shale ratios for the total outcrop. The core description will only be used for the 20 m interval that is exposed in the quarry. This was decided on the fact that no other information about subsurface data is used to calculate percentages and ratios for the other four outcrops and would skew the results of this research.

Facies Architecture

The outcrop begins at the quarry floor and is divided into 5 packages A-E, A being at the base and E being at the top of the quarry. Table 5 shows package thickness and facies type.

Table 5: Data table showing package thickness and facies type for the Hollywood Quarry.

Package	Thickness (m)	Facies
A	4.1	M1
B	1.53	M4
C	2.9	M2
D	1.85	M4
E	9	M2

Sand/Shale Ratio

The sand/shale ratio and the sandstone and shale percentages were calculated primarily off of the core description because the lateral bed thickness change does not vary significantly. The facies percentages for the outcrop are 21% facies 1, 61.5% facies 2, and 17.5% facies 4. The overall sandstone percentage is 71.5%, and the overall shale percentage is 28.5 with a sand/shale ratio of 2.5.

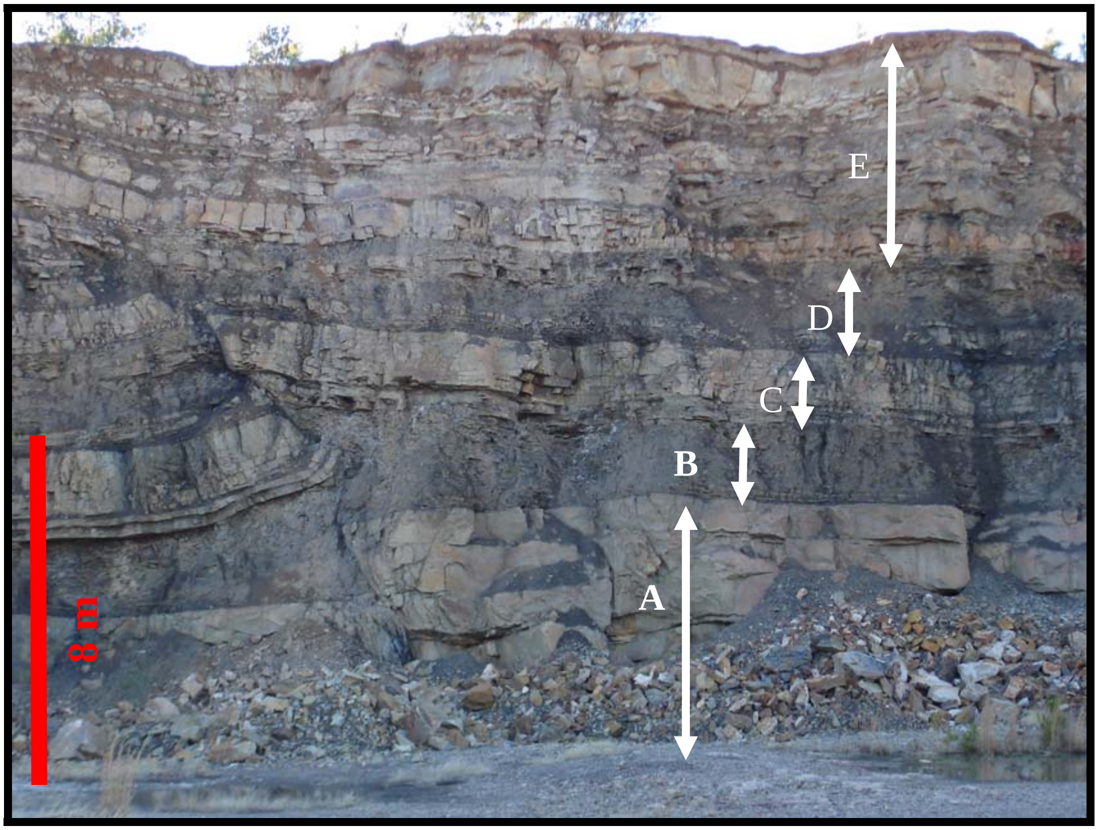

Figure 15: Photograph of Hollywood Quarry showing units A-E.

Lower Fan

The Baumgardner Quarry near Kirby is basically a good study of a lower fan outcrop. A few middle fan deposits can be recognized, while the majority of the deposits represent the lower fan. More thorough studies have to be done to provide all the details. As discussed in Chapter II, the end of the middle fan there is a transition to the lower fan and there is a zone of mixed deposit types, middle and lower. As also previously mentioned, the lower fan has two parts, upper and lower fan. The upper or inner part is characterized by having distributary channels, and the lower or outer is characterized part by lobe or sheet deposits. Fan avulsions are very common in the lower fan due to the extremely low gradient on the basin plain.

Because of this, the lower fan only has to build a small amount vertically to drastically change the basin floor gradient enough to re-route flows, know as compensational stacking patterns. If the avulsion is great enough to re-route the flows far enough away, the vertical sequence of deposits can be separated by thick intervals of laminated marine shales before the fan avulses back over.

Facies

Five different facies are present in the lower fan outcrop. The first two facies are only differentiated by the presence or lack of shale drapes. The facies are defined as the following:

Facies L1

Facies L1 is described as massive sandstones that are structureless, commonly normally graded, amalgamated, and have no shale drapes preserved, Figure 16. Sandstone percentage for this facies is approximately 95%.

Facies L2

Facies L2 is described as bedded sandstones that are structureless, commonly normally graded, amalgamated, and do contain shale drapes, Figure 17. Sandstone percentage for this facies is approximately 75%.

Facies L3

Facies L3 is sandy or muddy debrites that are formed from plastic and cohesion process such as: slides, slumps, debris flows, and slurry flows, shown in Figure 18. The sandstone percentage for this facies is 50%.

Facies L4

Facies L4 is shale that is laminated or interlaminated with very thin sandstones and siltstones, Figure 19. As described by Stelting et al. (2008), this facies records the very distal extent of the fan and has approximately 30% sandstone.

Facies L5

Facies L5 is marine shale that has little or no sand content, Figure 20. This facies is different from L4 because the shale is not deposited by turbulent flows but of pelagic sedimentation in many very thin deposits. Sandstone percentages for this facies are hard to calculate because the only place where the facies is located in the outcrop is a road that has been pulverized, but for statistical analysis 10% sandstone will be used as a gross approximation.

Figure 16: Photograph from Baumgardner Quarry with an arrow highlighting a Facies L1 that is 4 m thick.

Figure 17: Photograph from Baumgardner Quarry with an arrow highlighting a Facies L2 that is 4.5 m thick.

Figure 18: Photograph from Baumgardner Quarry with an arrow highlighting a Facies L3 that is 2.5 m thick.

Figure 19: Photograph from Baumgardner Quarry with an arrow highlighting a Facies L4 that is 4.2 m thick.

Figure 20: Photograph from Baumgardner Quarry with an arrow highlighting a Facies L5 that is 5 m thick. Facies L5 is finely laminated marine shale from pelagic sedimentation.

Baumgardner Quarry

This quarry is located 2 miles south of Kirby, and is actively used as a source of aggregate. The beds in the outcrop are tilted almost 90^{o} and exposes 194m with a strike cross-sectional view. The quarry had three benches excavated, but since the quarry was active at the time the data was collected, only the one bench could be described in detail. This outcrop is commonly used as a field guide stop. The only known work on this outcrop is from the Stelting et al. (2004). He used the outcrop as a field guide using the outcrop as an analog to distal turbidite reservoirs. Three distinctive units are easily seen when the outcrop is viewed. The first or lower unit is 49m thick and is described as lobe deposits based on the amount of amalgamated sandstones. The fewer amount of shales are in between the two cycles, and the distinctive compensational stacking pattern can be seen in Figures 21 and 22. Since the quarry was active at the time the data was collected, and only 24 m of this unit are described in detail from the second bench. The second or middle unit, shown in Figure 23, is laminated marine shale that is 33 m thick. The actual approximant amount of sandstone content is not known because the section is currently being used as a road for excavation equipment. The third or upper unit, Figures 23 and 24, is 105 m thick and is primarily unconfined sheet sand cycles of massive and bedded sandstones capped by shales. The cycles average about 15 m in thickness and can be as thick as 21 m (Stelting et al., 2004). These interpretations are based off the observation of the shale beds that separate different cycles.

Table 6: Data table showing package thickness and facies type for the Baumgardner Quarry.

Package	Thickness (m)	Facies	Package	Thickness (m)	Facies
A	1.3	L1	U	11.8	L1
B	1	L2	V	7.2	L2
C	2.5	L1	W	7.6	L4
D	2.5	L3	X	2.3	L1
E	.78	L2	Y	.85	L4
F	2.3	L1	Z	5.1	L1
G	2.42	L2	AA	4.7	L2
H	4.2	L1	BB	3.8	L1
I	1.04	L2	CC	3.4	L2
J	5	L1	DD	1.3	L4
K	5.5	L2	EE	11	L1
L	33.5	L5	CC	3.4	L2
M	7.6	L1	DD	1.3	L4
N	4.2	L4	EE	11	L1
O	1.7	L1	CC	3.4	L2
P	.85	L3	DD	1.3	L4
Q	6	L1	EE	11	L1
R	1.3	L3	CC	3.4	L2
S	5.1	L1	DD	1.3	L4
T	9.7	L2	EE	11	L1

Facies Architecture

The outcrop begins at the northeast side of the quarry and is divided into 31 packages A-EE. A is located at the base and EE is the stratigraphic top of the outcrop. Table 6 shows package thickness and facies type.

Sand/Shale Ratio

The sand/shale ratio and the sandstone percentages were calculated for each individual unit because the lower and upper units are separated by marine shale that was not deposited by a gravity flow. The facies percentages for the lower unit are 54% facies L1, 38% facies L2, and 8% facies L3. The overall sandstone percentage is 83.8% and a sand/shale ratio of 5.2. The middle unit is 100% facies L5 and has a sandstone percent of 10%. The sand/shale ratio for this unit is 0.11. The upper unit has a facies percentage of 57% facies L1, 26% L2, 3% facies L3, and 14% facies L4. The sandstone percentage is 79% and the sand/shale ratio is 3.8. For the entire outcrop the total amount of sandstone is 65% with a sand/shale ratio of 1.9.

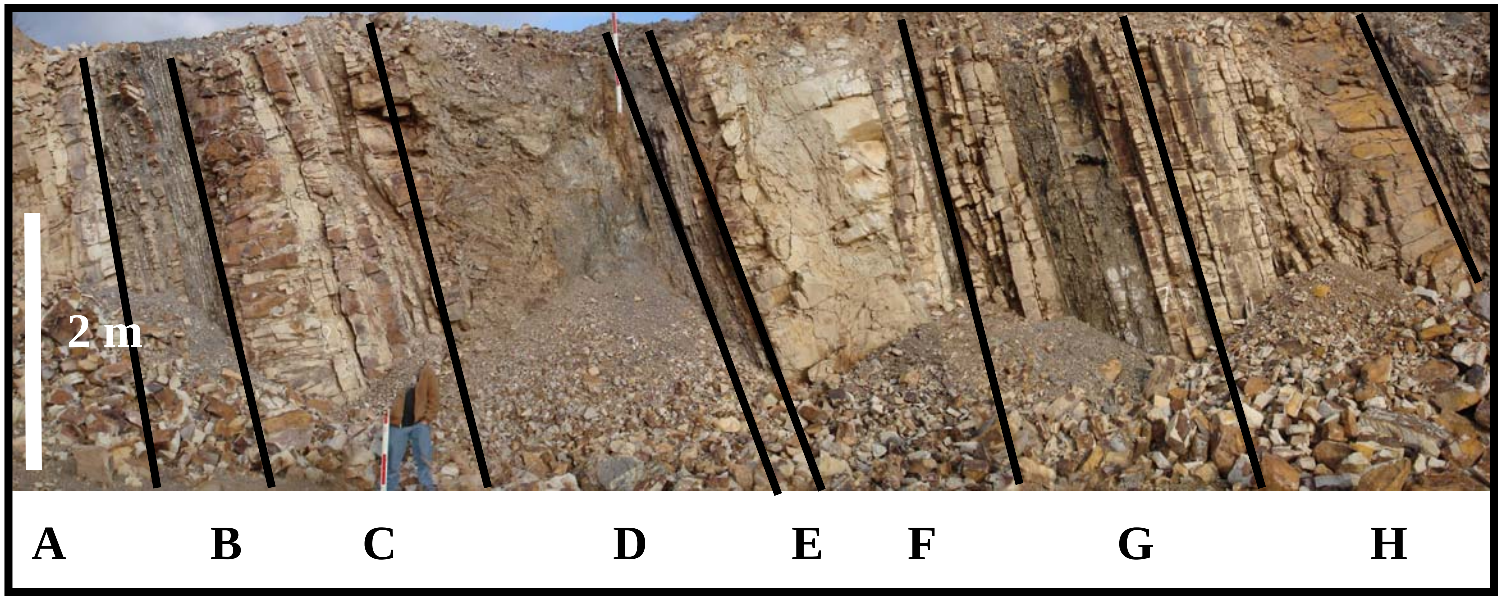

Figure 21: Outcrop photograph of the lower unit at the Baumgardner Quarry showing packages A-H. These deposits are compensational stacked indicating a closer proximity to the beginning of the lower fan.

Figure 22: Outcrop photograph of the lower unit at the Baumgardner Quarry showing packages H-K. These deposits are compensational stacked indicating a closer proximity to the beginning of the lower fan.

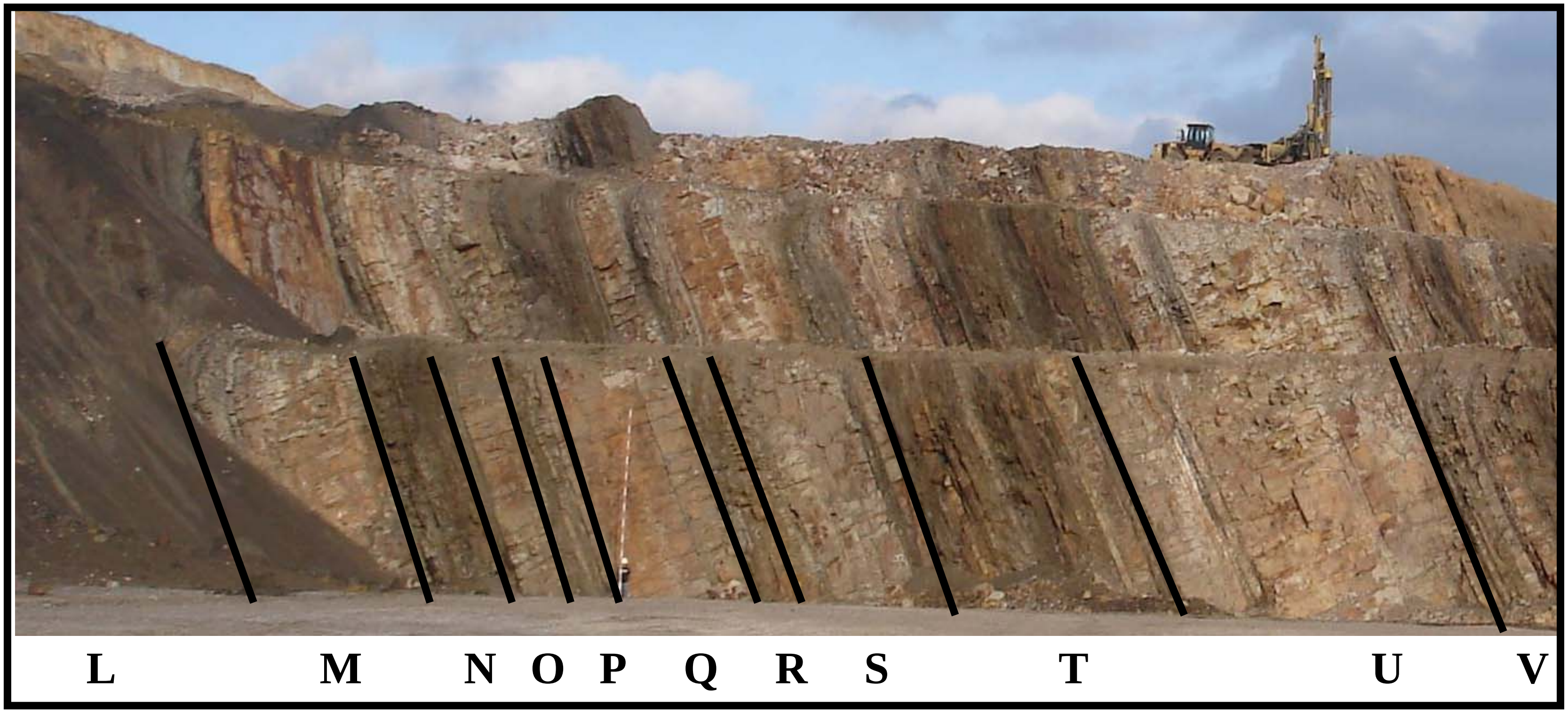

Figure 23: Outcrop photograph of the middle and upper unit at the Baumgardner Quarry showing packages L-V. These upper unit deposits contain more shale and are more parallel stacked beds which indicate a more distal deposit than those from the lower unit.

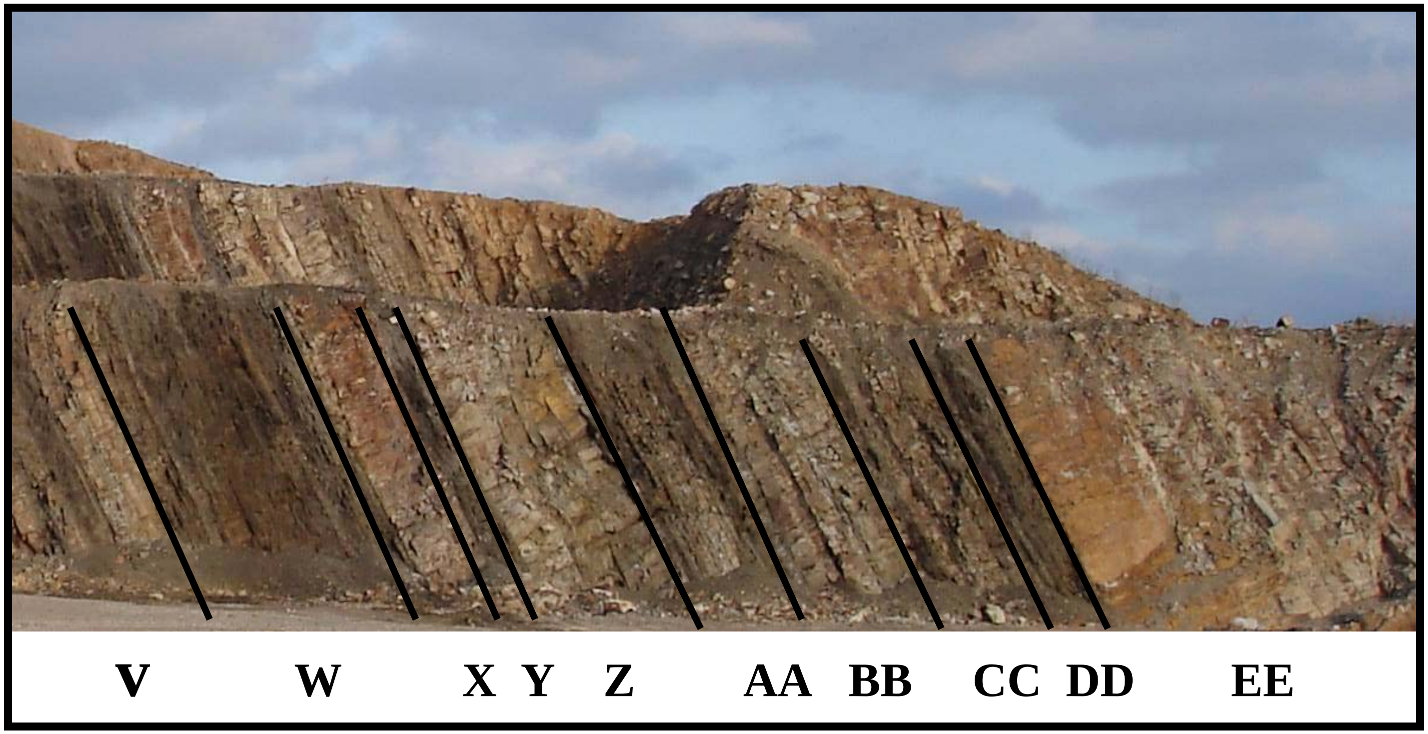

Figure 24: Outcrop photograph of the upper unit at the Baumgardner Quarry showing packages V-EE. These upper unit deposits contain more shale and are more parallel stacked beds which indicate a more distal deposit than those from the lower unit.

CHAPTER IV

OUTCROP COMPARISONS

Sandstone Distribution Patterns

This study has observed that there is an apparent sand/shale ratio and sandstone percentage change from the upper to the lower fan system in the Jackfork Group. By taking the sandstone percentage for each facies package and by plotting that against outcrop height, a facies distribution curve was created. The curves are used to visually compare how the upper, middle, and lower fan parts change in overall sandstone percentages and how the sandstone is distributed. Figure 25 shows sandstone distribution for the upper fan at Big Rock Quarry and shows a distinct 48 m sand rich lower section capped by a less sandy section. This pattern is consistent with an aggrading system that loses accommodation space causing the system to move laterally or prograde forward. Figure 26 shows sandstone distribution from the middle fan at Friendship Quarry, DeGray Lake Spillway, and Hollywood Quarry. By comparing all of the distribution curves for the middle fan outcrops, it is clear that the pattern shows repetitive fining upward sequences associated with lateral channel migration. Figure 27 shows the sandstone distribution of the lower fan at Baumgardner Quarry, and the curves pattern is evidence of sand rich lower unit that builds up and loses accommodation space forcing the system to avulse laterally before it can build up again and switch back. As observed from the different curves, the upper fan shows sandstone is distributed evenly and is quite concentrated throughout the height of the exposure. Sandstone beds are mainly amalgamated 10-30 m beds separated by a 1-3 m of fine-grained shale. This is clearly observed in the Gamma Ray log in Figure 28. The middle fan outcrops show similar patterns, except that the amalgamated sandstone beds are not as thick, 5-15 m. This is depending on if the sandstone beds were deposited in or out of the channel axis. The amount of shale between sandstone beds can be a little or a lot. For instance, the channel axis deposits have very little shale in between where as the channel margin and over-bank deposits are interbedded with as much as 70% shale. This observation is very clear when viewing Gamma Ray logs such as the Hollywood Quarry and DeGray Lake Spillway logs in Figure 29. Notice on the DeGray Lake Spillway log that the log outline is very serrated due to the high amount of interbedded sandstone and shale layers associated with channel margin and over-bank deposits. The lower fan is completely different than the two parts of the upper and middle fan. The distribution of sandstone is more concentrated in each of the individual units, or systems, but the overall complex has two systems separated by a massive marine shale bed, 33.5 m, that contains virtually no sand. The lower fan has a characteristic pattern of amalgamated and bedded sandstone sequences, unlike the random nature of the upper and middle fan.

Overall Sandstone Comparisons

The amount of sandstone change from the upper to lower fan is shown to be exactly what one would predict. The amount of sandstone decreases from upper to lower fan. The upper fan has approximately 77.5%, the middle fan has approximately 72.6%, and the lower fan has approximately 65.4%. Keep in mind that the actual amount of sandstone in the lower fan is much higher due to the 33.5 m marine shale layer that separates the actual sediment gravity flow deposits. The Sand/Shale Ratios for the Jackfork Group are 3.44 for the upper fan, 2.75 for the middle fan, and 1.8 for the lower fan.

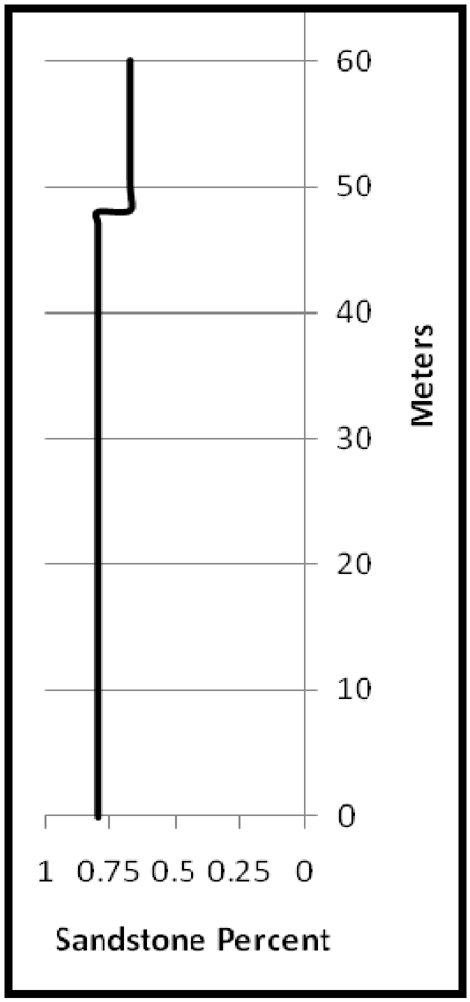

Figure 25: Sandstone Distribution curve for the upper fan at Big Rock Quarry showing a facies change at 48 m.

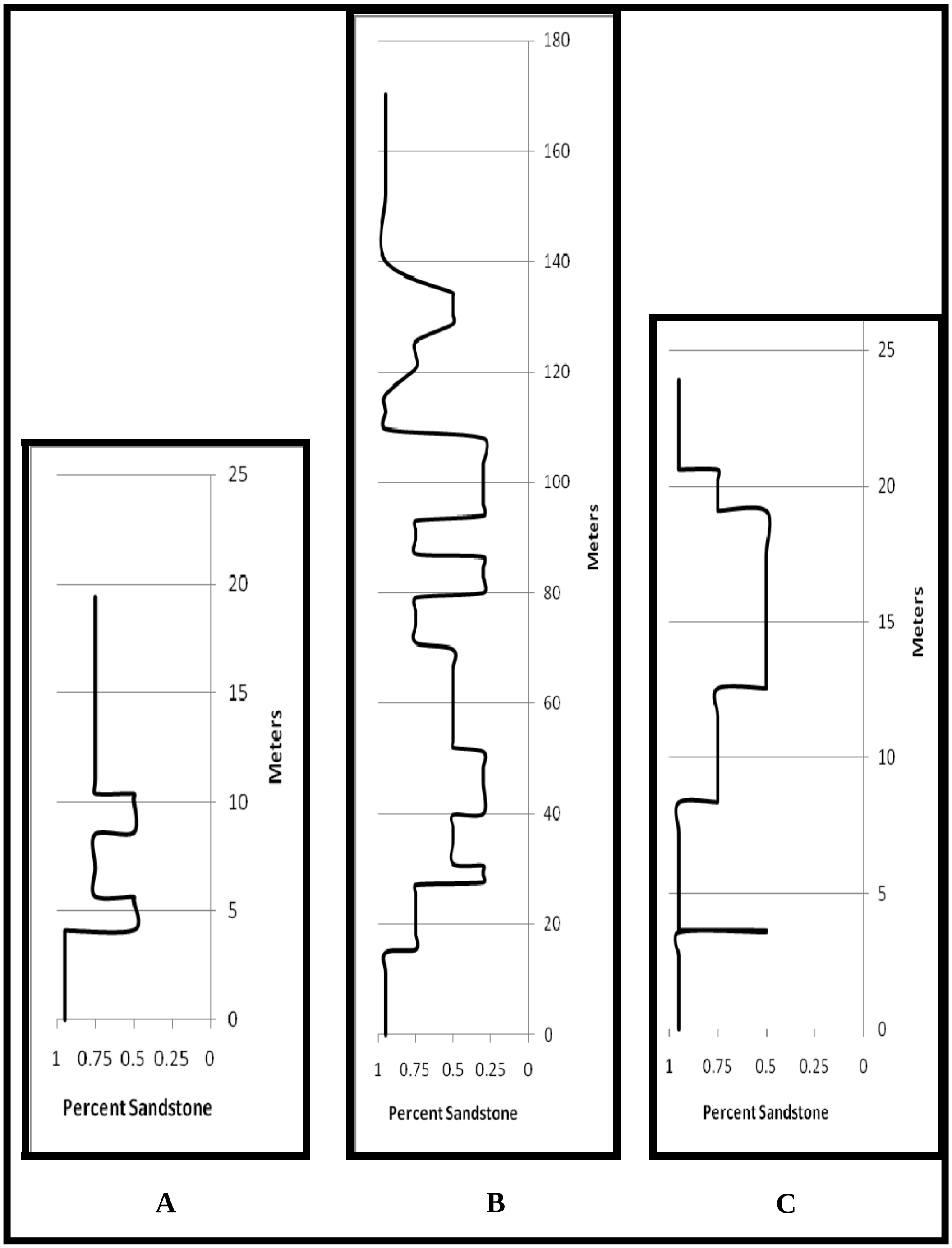

Figure 26: Sandstone distribution curves for the midde fan outcrops; A: Hollywood Quarry, B: DeGray Lake Spillway, C: Friendship Quarry.

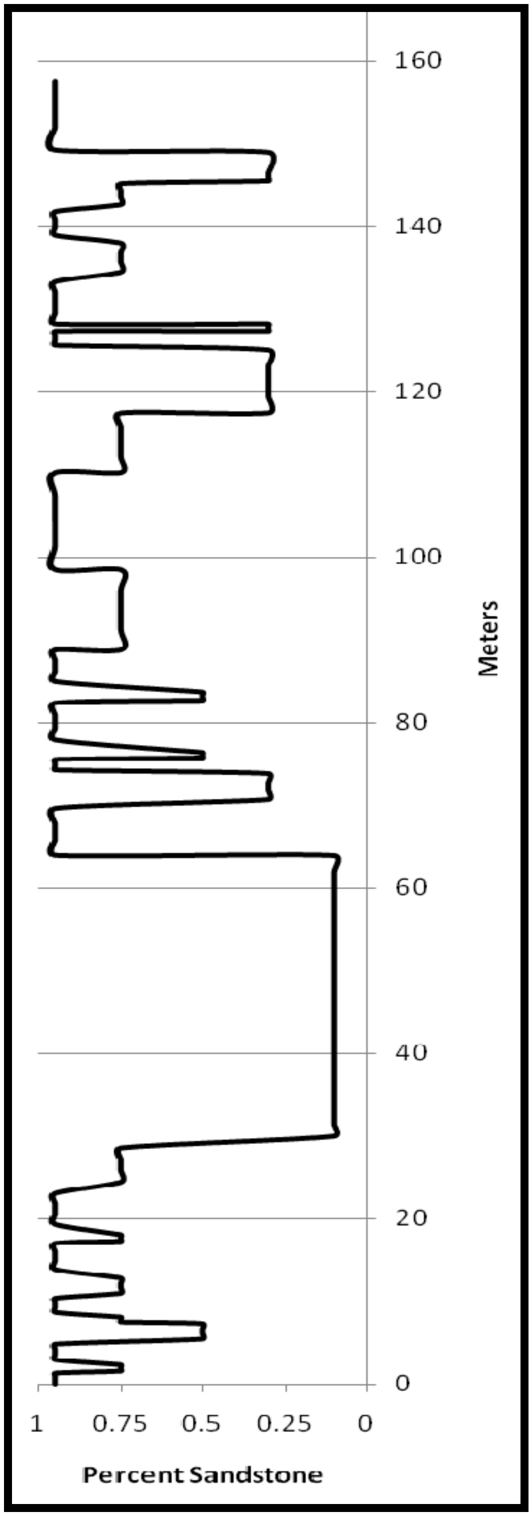

Figure 27: Distribution curve for the lower fan outcrop at Baumgardner Quarry.

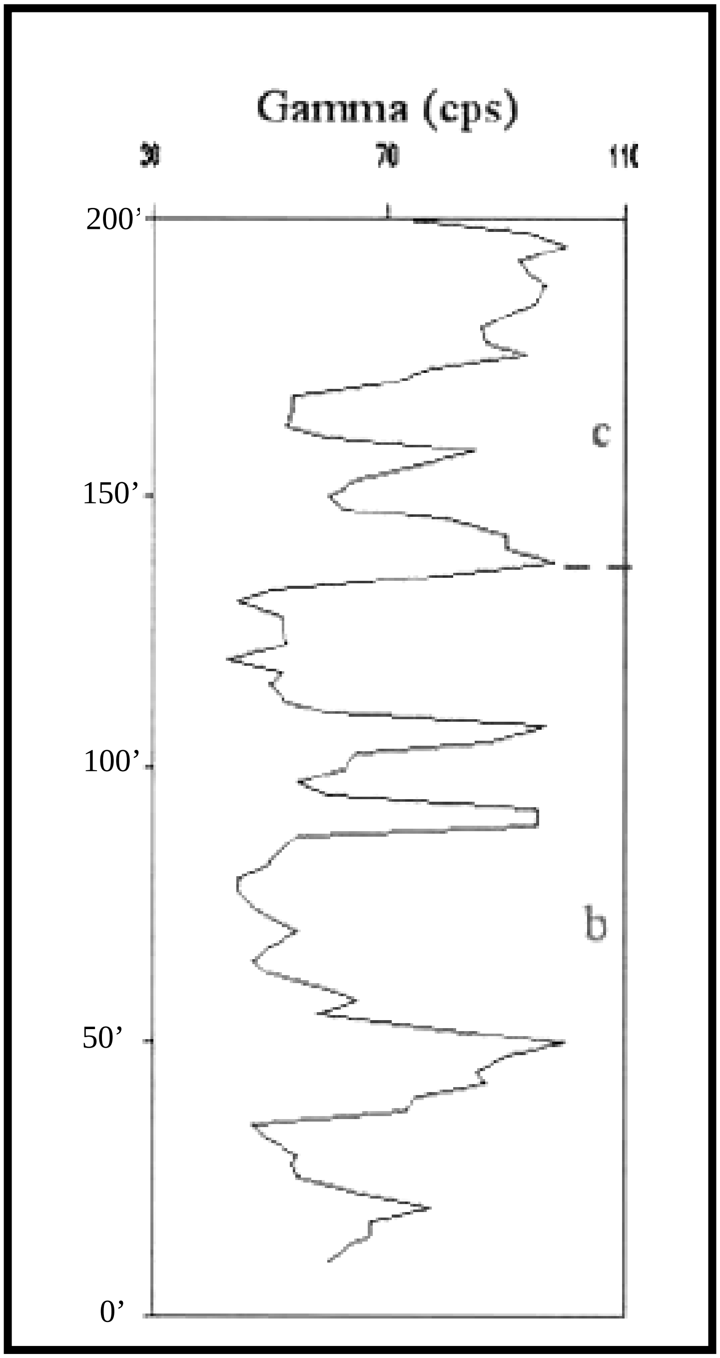

Figure 28: Outcrop Gamma Ray log of Big Rock Quarry. Height is in feet starting at the base of the outcrop (modified from Slatt and Stone, 2001).

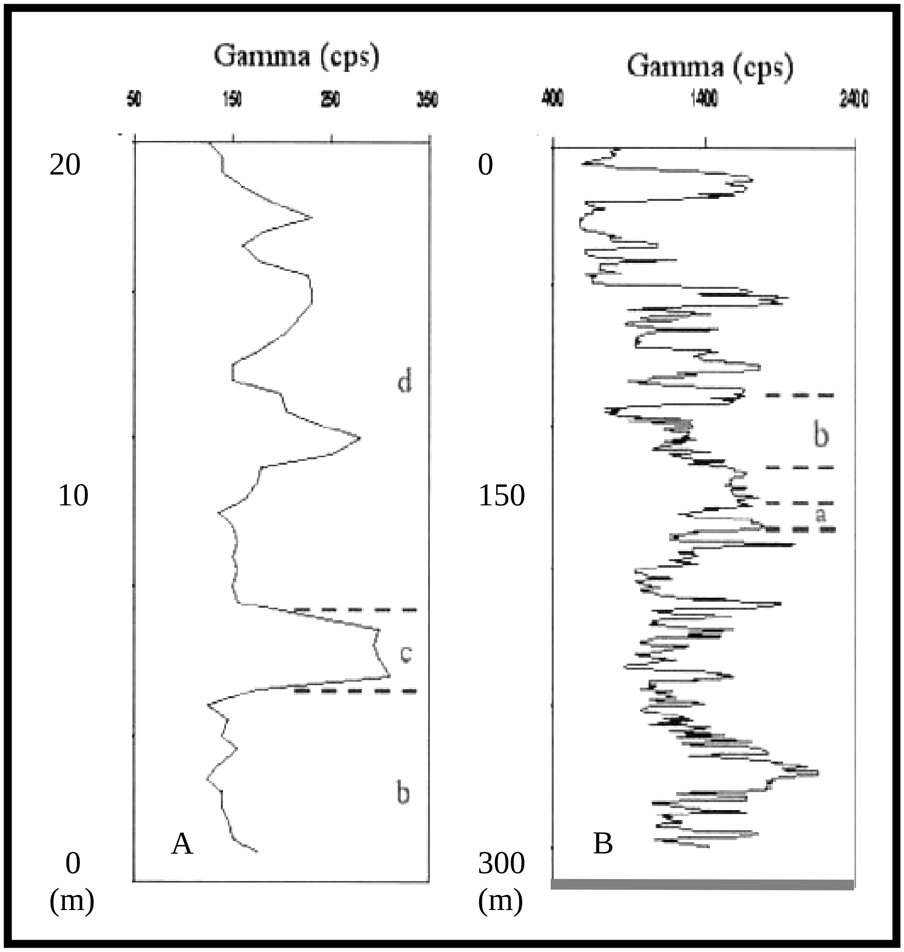

Figure 29: Gamma Ray log of A, Hollywood Quarry and B, DeGray Lake Spillway (modified from Slatt and Stone, 2001).

CHAPTER V

CONCLUSIONS

This study of the Arkansas Jackfork Group shows that there is an obvious change in the overall sandstone distribution from the upper to the lower fan. Even though most studies have focused on what types of deposits occur throughout the individual exposures, no previous study has focused on the changes of sandstone distribution throughout the formation. Table 7 shows the differences between the upper, middle, and lower fan units, such as facies type, sandstone percentages, and sand/shale ratios. When using the outcrops from the Jackfork Group as an analogue, a prediction such as if a sandstone reservoir is deposited in the upper, middle, or lower unit of a submarine fan can be made by observing the sandstone percentages and distribution patterns.

Table 7: Sandstone distribution and percentages for the upper, middle, and lower fan outcrops of the Arkansas Jackfork Group.

Fan Unit	Upper Fan	Middle Fan	Lower Fan
Outcrop Location	Big Rock Quarry	Friendship Quarry DeGray Lake Spillway Hollywood Quarry	Baumgardner Quarry
Facies	U1, U2	M1, M2, M3, M4,M5	L1, L2, L3, L4, L5
Sandstone Percent	77.5%	72.6%	65.4%
Sand/shale Ratio	3.44	2.75	1.8

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